REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
		Summary 1 June 95 - 31 May 96

4. TITLE AND SUBTITLE
Ultrasonic Characterization of High T_c and Other Unconventional Superconductors

5. FUNDING NUMBERS
PE 61153N
N0014-91-J-1211

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
ONR 331
800 North Quincy Street
Arlington, VA 33317-5660

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release;
distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Ultrasonic techniques have been used to characterize the properties of high T_c superconductors. A model is being developed to explain the radiation losses from a resonating fused silica sample. A new very sensitive resonant technique was developed for studying vortex motion in the superconducting state of an untwinned single crystal of YBCO. Evidence is obtained for a transition from a soft vortex system to a rigid strongly interacting vortex system in the vicinity of the superconducting transition temperature. A percolation model developed in our group to describe surface acoustic wave SAW attenuation in a granular superconducting film was modified to include the resistivity of the individual grains in a matrix of Josephson junctions. SAW measurements using a pontoon technique on both a single crystal and a thin film of YBCO demonstrate the importance of pinning sites in determining the nature of a vortex transition; the vortex system will undergo a depinning transition if the pinning density is large and a melting transition if it is small. Resonant ultrasonic spectroscopy data obtained by the UCLA group as a function of gas pressure has been analyzed. A preliminary two dimensional model for the radiation impedance qualitatively predicts the linear increase in attenuation with gas pressure, the increase in attenuation for higher molecular masses of the surrounding gas and the larger attenuation for torsional modes than for compressional modes. It appears that a three dimensional model will be necessary in order to obtain quantitative agreement.

14. SUBJECT TERMS
High T_c Superconductors, YBCO, ultrasonic techniques, surface acoustic waves SAW, vortex melting transition, vortex depinning transition, resonant ultrasonic spectroscopy, radiation impedance

15. NUMBER OF PAGES
8

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	

Ultrasonic Characterization of High T_c and Other Unconventional Superconductors

Moisés Levy

ANNUAL SUMMARY REPORT

June 1, 1995 to June 30, 1996

A. Description of Project

The objectives of this research project are to characterize the properties of high T_c superconductors and other unconventional superconductors using ultrasonic techniques in order to provide insights into the mechanisms that are responsible for the unusual superconducting properties of high T_c superconductors.

B. Approaches Taken

A new very sensitive resonance technique was developed for investigating small platelet single crystal samples of high T_c superconductors.

Bulk acoustic wave attenuation and velocity measurements as a function of temperature and magnetic field were performed on melt textured samples of $Y_1Ba_2Cu_3O_7$.

Surface acoustic waves were used to investigate single crystals and thin films of $Y_1Ba_2Cu_3O_7$.

The resonant ultrasonic spectrometer technique was used to determine the elastic constants of small samples of single crystal Si.

The radiation impedance of RUS modes was analyzed.

C. Accomplishments

A new technique was developed for studying vortex motion in the superconducting state of an untwinned single crystal of $Y_1Ba_2Cu_3O_7$ whose dimensions are 1 mm by 1 mm by 50 μm. The crystal is brought into close proximity of a 5 MHz x-cut quartz transducer. It is pressed by two 25 μm strands of varnish to the transducer, which is held by copper wires. This

ensemble has a resonant frequency of 3 MHz. The quality factor Q of the system is the measured as a function of temperature and magnetic field in the vicinity of the superconducting transition temperature. Quality factors as high as 10^4 may be achieved in this system; and, the change in Q produced by a change in attenuation in the superconducting sample is proportional to Q. This is how the sensitivity of the measurements is enhanced. A sensitivity of 1×10^{-4} dB/cm can be achieved for the system which translates to a sensitivity of 5×10^{-3} dB/cm for the superconducting sample. The measurements were done with the magnetic field parallel to the ab plane of the crystal. The motion of the transducer was parallel to the c-axis. This resulted in a Lorentz force parallel to the ab plane so that the vortex motion was also along the ab plane. As a function of magnetic field at a constant temperature below T_c, the attenuation was proportional to the magnetic field below 0.2 T, which indicates that the interaction is proportional to the vortex density and therefore the interaction is, essentially, with individual, weakly interacting vortices, or a soft vortex system. At fields above 0.28 T the attenuation is proportional to approximately the cube of the applied field. This is probably due to the fact that with increasing vortex density the interaction between vortices becomes stronger leading to a quadratic increase in the viscosity of the system. Thus, at around 0.2 to 0.28 T there is a transition from a soft vortex system to a rigid, strongly interacting vortex system. Preliminary measurements very close to T_c, appear to indicate that slightly below the upper critical field the vortex lattice undergoes another transition from the rigid vortex system to the soft vortex system, as predicted by a recent theoretical model in a paper we submitted to Philosophical Magazine Letters.

Surface acoustic wave SAW measurements were made on a granular thin film of YBCO. The film is modeled as a two-dimensional network of Josephson junctions. A percolation model developed in our group to describe the SAW attenuation was modified to take into account the

resistivity of the grains in the normal state, and a reasonable fit to the data was obtained.

SAW measurements, using the pontoon technique described in a previous report were continued on an untwinned single crystal platelet of YBCO, and preliminary evidence for a peak in attenuation associated with a melting transition in this crystal with a low density of pinning sites is verified. Pontoon SAW measurements on a thin film of YBCO grown epitaxially on a $LiNbO_3$ subtrate were also continued. Since the film had a large density of vortex pinning sites, the behavior of the observed peak in attenuation for different applied constant magnetic fields, as a function of temperature, was consistent with a depinning transition, since the magnitudes of the peak depended on the square of the applied magnetic field. This dependence is expected from thermally activated flux flow models, where the attenuation can be shown to be proportional to the shear modulus of the vortex system which is proportional to the square of the flux density. The field dependence of the magnitude of the peaks observed in the untwinned single crystal was larger than quadratic which may imply that there is increased defect motion in the vortex system which could be associated with a melting transition. Thus, these two sets of measurements demonstrate the role played by pinning sites in determining whether a vortex system will undergo a depinning transition, a melting transition, or both, depending on the density of pinning sites.

The data on resonant ultrasonic spectroscopy RUS that the UCLA group have obtained on fused silica as a function of pressure for different gas compositions has been analyzed. For both compressional and torsional modes, the inverse of the Q's appear to be linearly dependent on the applied pressure. If it is assumed that this effect is being produced by the radiation of sound into the surrounding gas, then one can deduce that the radiation resistance is linearly dependent on the pressure; and, furthermore, the data also show that the radiation resistance increases monotonically as the molecular mass M of the surrounding gas is increased. These

effects appear to be larger for the compressional modes than for the torsional modes. The velocity of the individual vibrating rectangular surfaces of the sample have been approximated by the product of two orthogonal sine functions for the torsional modes and two orthogonal cosine functions for the compressional modes. The radiation impedance of these surfaces has been calculated numerically. It is found that this model yields that the radiation resistance increases linearly with pressure, and increases with the molecular mass of the gas. However, the experimental data show a change that increases linearly with M for the torsional modes and as $M^{3/4}$ for the compressional modes, while the model gives an increase as $M^{1/2}$; and, although, the model does predict a larger value for the compressional modes it is not as large as is found experimentally. It appears that it may be necessary to solve the problem three dimensionally instead of modeling the rectangular parallelopiped sample as six independent vibrating surfaces which do not interact with each other. It was assumed that this was a valid model since the wavelengths in the gases are much larger than the individual dimensions of the sample, and the directivity would be mostly perpendicular to the vibrating surfaces.

OFFICE OF NAVAL RESEARCH
PUBLICATIONS/PATENTS/PRESENTATIONS/HONORS REPORT
for
01 June 95 through 31 May 96

Contract/Grant Number: N00014-91-J-1211

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a. Number of papers submitted to refereed journals but not yet published: 5

b. Number of papers published in refereed journals (ATTACH LIST): 1

c. Number of books or chapters submitted but not yet published: 1

d. Number of books or chapters published (ATTACH LIST): 1

e. Number of printed technical reports & non-refereed papers (ATTACH LIST): 3

f. Number of patents filed: 0

g. Number of patents granted (ATTACH LIST): 0

h. Number of invited presentations at workshops or professional society meetings: 1

i. Number of contributed presentations at workshops or professional society meetings: 7

j. Honors/awards/prizes for contract/grant employees, such as scientific society and faculty awards/offices (ATTACH LIST): 0

k. Number of graduate students supported at least 25% this year this contract/grant: 4

l. Number of post docs supported at least 25% this year this contract/grant: 1

How many of each are females or minorities? These six numbers are for ONR's EEO/Minority Reports. Minorities include Blacks, Aleuts, Amindians, etc., and those of Hispanic or Asian extraction/nationality. The Asians are singled out to facilitate meeting reporting semantics re "underrepresented".

Graduate student FEMALE:	1	Post doc FEMALE:	0
Graduate student MINORITY:	0	Post doc MINORITY:	0
Graduate student ASIAN E/N:	1	Post doc ASIAN E/N:	0

OFFICE OF NAVAL RESEARCH
PUBLICATIONS/PATENTS/PRESENTATIONS/HONORS REPORT
1 June 1995 through 31 May 1996

Ultrasonic Characterization of High T_c and Other Unconventional Superconductors
Moisés Levy

a. Number of Papers Submitted to Referred Journals but not yet published: 5

1. "Ultrasonic Attenuation and Sound Velocity Changes in a Superconducting $La_{2x}Sr_xCuO_4$ Single Crystal," Hong Zhang, Mark J. McKenna, Carsten Hucho, Bimal K. Sarma, Moises Levy, T. Kimura, K. Kishio and K. Kitazawa, Physica B (to be published).

2. "On the Peak Effect and Vortex Lattice Melting in YBCO," Carsten Hucho and Moises Levy, Philosophical Magazine Letters (to be published).

3. "Ultrasonic Studies on UPt_3 in High Magnetic Fields," S. W. Lin, I. Kouroudis, A.G. M. Jansen, P. Wyder, B. Luthi, D. G. Hinks, J. B. Ketterson, M. Levy and Bimal K. Sarma, SCES-95, Conference, Goa, India, Sept. 27-30, 1995, Physica B (to be published).

4. "Ultrasonic Studies of Superconducting and Magnetic Transitions in $La_{2-x}Sr_XCuO_4$ Single Crystal," Hong Zhang, Mark J. McKenna, Carsten Hucho, Bimal K. Sarma, Moises Levy, T. Kimura, K. Kishio and K. Kitazawa, SCES-95 Conference, Goa, India, Sept. 27-30, 1995, Physica B (to be published).

5. "Transitions in the Vortex Lattice in $YBa_2Cu_3O_{7-\delta}$ Single Crystal," C. Hucho and M. Levy, (submitted to Phys. Rev. Letters).

b. Number of Papers Published in Referred Journals: 1

1. "Ultrasonic Velocity and Attenuation Measurements at the Metamagnetic Transition in Upt_3," S. W. Lin, I. Kouroudis, A. G. M. Jansen, P. Wyder, B. Luthi, D. G. Hinks, J. B. Ketterson, M. Levy, and Bimal K. Sarma, Journal of Low Temperature Physics 101, 635-640 (1995).

c. Number of Books or Chapters Submitted But Not Yet Published: 1

1. "High Field Ultrasonic Measurements on UPt_3," S. W. Lin, I. Kouroudis, A. G. M. Jansen, P. Wyder, B. Luthi, D. G. Hinks, J. B. Ketterson, M. Levy and Bimal K. Sarma (to be published in Physical Phenomena at High Magnetic Fields II, World Publishing Co., Singapore).

d. Number of Books or Chapters Published: 1

1. IEEE 1995 Ultrasonics Symposium Proceedings, 1636 pages, (95CH35844, IEEE, Piscataway, N. J., 1995).

e. Number of Printed Technical Reports and Non-referred papers: 3

1. "Design Dependent Transition Behavior for Superconducting Transducers and Reflectors." H. Fredricksen, D. Ritums, N. J. Wu, X. Y. Li, J. Willis, A. Ignatiev, B. K. Sarma and M. Levy, 1995 IEEE Ultrasonics Symposium Proceedings, pages 555-558, (95 CH35844, M. Levy, S. C. Schneider and B. R. McAvoy, editors, IEEE, Piscataway, N. J. 1995).

2. "Surface Acoustic Wave Investigation of Mixed State Phases in $Y_1Ba_2Cu_3O_7$," C. Hucho, J. Feller, R. Gaffney, M. McKenna, B. Sarma and M. Levy, 1995 IEEE Ultrasonics Symposium Proceedings, pages 559-561, (95 CH35844, M. Levy, S. C. Schneider and B. R. McAvoy, editors, IEEE, Piscataway, N. J. 1995).

3. "Ultrasonic Studies of Superconducting and Magnetic Transitions in a $La_{2-x}Sr_xCuO_4$ Single Crystal," H. Zhang, M. J. McKenna, C. Hucho, B. K. Sarma, M. Levy, T. Kimura, K. Kishio and K. Kitazawa, 1995 IEEE Ultrasonics Symposium Proceedings, pages 563-566, (95 CH35844, M. Levy, S. C. Schneider and B. R. McAvoy, editors, IEEE, Piscataway, N. J. 1995).

f. Number of Patents Filed: 0

g. Number of Patents Granted: 0

h. Number of Invited Presentations at Workshops or Professional Society Meetings: 1

1. "Ultrasonic Measurements in High T_c Superconductors," M. Levy, Phonon 95, Fourth International Conference on Phonon Physics and Eighth International Conference on Phonon Scattering in Condensed Matter, Sapporo, Japan, 23-28 July (1995). INVITED.

i. Number of Presentations at Workshops or Professional Society Meetings: 7

1. "Design Dependent Transition Behavior for Superconducting Transducers and Reflectors." H. Fredricksen, D. Ritums, N. J. Wu, X. Y. Li, J. Willis, A. Ignatiev, B. K. Sarma and M. Levy, 1995 IEEE Ultrasonics Symposium, Seattle, Washington, November 7-10, 1995.

2. "Surface Acoustic Wave Investigation of Mixed State Phases in $Y_1Ba_2Cu_3O_7$," C. Hucho, J. Feller, R. Gaffney, M. McKenna, B. Sarma and M. Levy, 1995 IEEE Ultrasonics Symposium, Seattle, Washington, November 7-10, 1995.

3. "Ultrasonic Studies of Superconducting and Magnetic Transition in a $La_{2-x}Sr_xCuO_4$ Single Crystal," H. Zhang, M. J. McKenna, C. Hucho, B. K. Sarma, M. Levy, T. Kimura, K. Krishio and K. Kitazawa, 1995 IEEE Ultrasonics Symposium, Seattle, Washington, November 7-10, 1995.

4. "Preliminary Studies of Resonant Ultrasound Spectroscopy of Silicon and $YBa_2Cu_3O_7$ Single Crystals," Hong Zhang, Mark J. McKenna, Bimal K. Sarma and Moises Levy, Second Annual Meeting of the Consortium on Resonant Ultrasound Spectroscopy, held August 24 and 25, 1995 in Santa Fe, NM.

5. "Ultrasonic Studies on UPt_3 in High Magnetic Fields," S. W. Lin, I. Kouroudis, A.G. M. Jansen, P. Wyder, B. Luthi, D. G. Hinks, J. B. Ketterson, M. Levy and Bimal K. Sarma, SCES-95 Conference, Goa, India, Sept. 27-30, 1995.

6. "Ultrasonic Studies of Superconducting and Magnetic Transitions in $La_{2-x}Sr_XCuO_4$ Single Crystal," Hong Zhang, Mark J. McKenna, Carsten Hucho, Bimal K. Sarma, Moises Levy, T. Kimura, K. Kishio and K. Kitazawa, SCES-95 Conference, Goa, India, Sept. 27-30, 1995.

7. "Surface Acoustic Wave Investigation of Mixed State Phase in $Y_2Ba_3Cu_3O_7$," C. Hucho, J. Feller, R. Gaffney, M. McKenna, B. Sarma and M. Levy, 1995 World Congress on Ultrasonics, Berlin, Germany, Sept. 3-7, 1995.

8. "Radiation Impedance of RUS modes in Fused Silica and KCℓ, J. Herro, H. Zhang, C. Hucho, D. Beck, M. Levy, D. Isaak, J. D. Carnes, and O. Anderson, 131st Meeting of ASA, 13-17 May, 1996, Indianapolis, IN.

j. Honors/Awards/Prizes for Grant employee: 0

k. Total Number of Graduate Students and Post Docs Supported at Least 25% This Year on This Grant:

Graduate Students: 4	Post Docs: 1
Jeffrey Feller	Mark J. McKenna
Ron Gaffney	
Joseph Herro	
Hong Zhang	